Microlithographic Reduction Projection Catadioptric Objective

Cross-References to Related Applications - Not applicable.

Statement Regarding Federally Sponsored Research or Development - Not applicable.

Reference to a Microfiche Appendix – Not applicable.

Background of the Invention

Technical Field

The invention concerns a microlithographic reduction projection catadioptric objective comprising an even number greater than two of curved mirrors, being devoid of planar folding mirrors and featuring an unobscured aperture.

Background Art

Such objectives are known from European Patent document EP 0 779 528 A (Fig. 3) as variants of pure catoptric objectives, with six mirrors and three lenses. All optical surfaces are symmetric to a common axis and an object plane and an image plane are situated on this axis upstream and downstream of the objective. However, all but one of the mirrors need to be cut off sections of bodies of revolution, so that mounting and adjustment face difficulties. The lenses serve only as correcting elements of minor effect. The most imageward mirror is concave.

US Patent 4,701,035 (Fig. 12) shows a similar objective. This one, however, has nine mirrors, two lenses and two intermediate images. The object plane and image plane are situated within the envelope of the objective.

In both cases the image field is an off-axis ring sector.

A fully axially symmetric catadioptric objective is known from German Patent document DE 196 39 586 A (corresponding to US Patent Application Serial No. 09/263,788), e. g., with

two opposing concave mirrors, an image field centered at the axis, and a central obscuration of the aperture.

Another type of catadioptric objective suitable for microlithographic reduction projection has only one concave mirror, but at least one folding mirror, and is known from US Patent 5,052,763 and European Patent document EP 0 869 383A inter alia and is referenced here as "h-design".

US Patent 5,323,263 discloses a microlithographic reduction projection catadioptric objective with multiple folding mirrors, where an intermediate image is arranged subsequent to a first concave mirror and a singly passed lens group.

US Patent 5,575,207 and US Patent 4,685,777 show very similar multiply folded catadioptric objectives.

Summary of the Invention

It is an object of the invention to provide a generic objective of good capabilities of chromatic correction for typical bandwidths of excimer laser light sources, which allows for a high imageside numerical aperture, and which reduces complexity of mounting and adjusting.

The solution to this problem is found in the present invention.

Brief Description of the Drawings

The invention is described in detail with respect to the drawings, wherein:

Fig. 1 shows a front end of an objective;

Fig. 2 shows the lens plan of a version of the objective; and

Fig. 3 shows the lens plan of another version of the objective.

Detailed Description of Preferred Embodiments

An important concept of the present invention is to replace the front end of an "h-design" objective with a different front end that provides a single axis system.

In the simplest version of this new front end, set up to be part of a -0.25 reduction. 0,75 image side NA system with a 7 mm x 26 mm rectangular image field size, the optical elements are shown in the lens section of Fig. 1. This catadioptric partial system provides a virtual image on the right hand side, which has enough axial chromatic aberration to compensate for a conventional focusing lens group that forms a 0.75 NA image. A real pupil or aperture plane is formed on the right hand end of the system. The system shown has enough Petzval sum so that the focusing lens group can be made up of mostly positive power lenses.

There is only one field lens LI in this system, which is close to the object plane (Ob) end of the system. That location is an advantage with respect to lens heating. There are no aspherics in this front end, and none are needed. The mirrors Ml to M4 are all spherical and coaxial to the common optical axis. It is possible to correct this front end system for spherical aberration of the pupil, but that requires a somewhat larger concave mirror than shown here. Spherical aberration can as well be corrected in the focusing lens group and therefore the size of the concave mirror M3 is minimized. Decreased size of mirror M3 simplifies the mechanical construction of the system. In the example of Fig. 1, the concave mirror M3 has an illuminated area that is about 165mm wide in the plane of the drawing and about 500 mm in the orthogonal direction, for a 7 mm x 26 mm image field size.

The greatest distance of any ray from the common optical axis is 370 mm in this example. This is substantially less than for many designs of the "h-design" type, where the concave mirror thickness and mount thickness must be added in to the sideways ray path

distance after the fold mirror, from the axis to the concave mirror. The package envelope of this new design is more attractive.

More axial chromatic aberration and Petzval curvature can be introduced by the front end (FE) than in the example of Fig. 1, by increasing the power of the negative lens L2 near the concave mirror Ml. A strong lens L2 however, tends to introduce too much overcorrected spherical aberration and makes the intermediate image aberrations too large. Thus, a better version of the design has two concave lenses near the concave mirror.

The field lens LI near the object plane Ob can also be split into two weaker lenses, to help control pupil aberration. Finally, the convex mirror M2 that is near the reticle (Ob) can be split off from the field lens LI surface and made to be a separate optical element. This more complicated design is capable of better performance.

It is possible to make this system meet all of the first-order specifications of a typical microlithographic objective as well as correct for Petzval curvature, and axial and lateral color correction, with only positive lenses in the telecentric focusing group (TFG). An example is shown in Fig.2, without any other kind of aberration correction. The lens heating is substantially uniform, as the beam diameter is large on all the lenses L21 to L29.

Fig. 3 shows a further embodiment example. The front end FE' features a field lens group split into 3 lenses L31 to L33, which helps achieve a good quality telecentricity. Also, the focussing lens group (FLG') now has more lenses L36 to L44. This focussing lens group FLG' has a few asphcrics. There are also some aspherics in the catadioptric front end FE' of the design that simplify correction, though they are not compulsory. The large mirror M33 is still a sphere, as this simplifies production.

Preferred locations of the aspheric surface are near an aperture or pupil plane, namely on mirror M31 or on lenses L34, L35, where the marginal ray height exceeds 80% of the height of the neighboring aperture, and on the other hand on some distant locations with marginal ray height less than 80% of the height of the next aperture. Examples of the latter are surfaces of the field lens group or of the last two lenses next to the image plane Im.

The polychromatic r.m.s. wavefront error value in this design now varies from .05 to 0.13 waves over a 26 X 7 mm field at .75 NA in a 4X design.

The catadioptric front end FE' is now somewhat more complicated than in Figs. 1 and 2. The design is both side telecentric and corrected for pupil aberration and distortion. The working distance is 34 mm on the reticle end (Ob) and 12 mm on the wafer end (Im). The system length is about 1200 mm.

The focusing lens group FLG' is almost all positive lenses (except L41), with no strong curves. The very large amount of aberration at the intermediate image is because the two concave lenses L31, L35 next to the concave mirror M31 do not have the optimum bending under this aspect.

Table I provides lens data for this embodiment.

Mechanical construction of the lens barrel for this type of objective is very advantageous when compared with catadioptric systems with folding of the optical axis (as "h-design" etc.). Here, only the mirrors M32 and M33 cannot be full disks. Mirror M33, however, can be extended to a full annular body that can be mounted in a rotationally symmetric structure. The barrel must be cut between the lenses L33 and L36 at a lower side of the drawing of Fig. 3 to provide passage to the light beam, but generally can be cylindrical. Only mirror M33 must be positioned outside this cylindrical barrel, but at a very moderate distance.

With "h-designs", a similar effect needs additional folding. Folding mirrors are generally not desirable, as they cause intensity losses and quality degradation of the light beam, and production costs and adjustment work without benefit to image quality.

It is possible to produce mirror M33 as an annular blank, and it can be mounted as this annular part in a cylindrical barrel that is extended in diameter in this area.

It can be seen that concave spherical mirror M33 is the only mirror extending outside of a cylindrical envelope scribed around all the lenses that has the radius of the lens of greatest radius. This shows again that this type of objective is suitable for mounting in a compact cylindrical barrel of high intrinsic rigidity.

The lens material in the given examples is calcium fluoride, fluorspar. Other materials standing alone or in combinations, may be used, namely at other wavelengths of excimer lasers. Quartz glass, eventually suitably doped, and fluoride crystals are such suitable materials.

Four, six and eight or more mirror objective designs known in the field of EUV lithography are generally suitable as starting designs for the front end group of the invention, with the eventual deviation that a virtual image instead of a real image is provided.

These embodiments are not intended to limit the scope of the invention. For example, in addition to curved mirrors, planar folding mirrors may occasionally be introduced into the system according to the invention.

All the features of the different claims can be combined in various combinations according to the invention.

Table 1

```
CODE V> lis
     Shafer-design .75NA.4x.75mm Obj.-hight
                RDY              THI     RMD        GLA              CCY   THC   GLC
 > OBJ:        INFINITY         34.000000                            100   100
     1:        147.23281        21.000000          'CAF-UV'          100   100
     2:        236.79522         1.000000                            100   100
     ASP:
     K  :       0.000000     KC :      100
     IC :        YES         CUF:    0.000000    CCF:      100
     A  :0.273300E-07        B  :0.201130E-11    C  :-.871260E-16    D  :0.118100E-19
     AC :        100         BC :      100       CC :      100       DC :      100

     3:        145.44401        27.000000          'CAF-UV'          100   100
     4:        224.64885        51.185724                            100   100
     5:       -223.00016        25.004072          'CAF-UV'          100   100
     6:       -184.59445       162.666291                            100   100
     7:        -97.23630        12.000000          'CAF-UV'          100   100
     8:       -928.69926        24.980383                            100   100
     9:        -75.28503        15.000000          'CAF-UV'          100   100
    10:       -116.14787         3.000000                            100   100
    11:       -134.28262        -3.000000   REFL                     100   100
     ASP:
     K  :       0.000000     KC :      100
     IC :        YES         CUF:    0.000000    CCF:      100
     A  :0.474810E-08        B  :0.506570E-12    C  :-.284590E-17    D  :0.934830E-21
     AC :        100         BC :      100       CC :      100       DC :      100

    12:       -116.14787       -15.000000          'CAF-UV'          100   100
    13:        -75.28503       -24.980383                            100   100
    14:       -928.69926       -12.000000          'CAF-UV'          100   100
    15:        -97.23630      -162.666291                            100   100
    16:       -184.59445       -25.004072          'CAF-UV'          100   100
    17:       -223.00016       -11.195502                            100   100
    18:       -363.91714        11.195502   REFL                     100   100
     ASP:
     K  :       0.000000     KC :      100
     IC :        YES         CUF:    0.000000    CCF:      100
     A  :-.107960E-07        B  :0.170830E-13    C  :-.328180E-16    D  :0.143630E-20
     AC :        100         BC :      100       CC :      100       DC :      100

    19:       -223.00016        25.004072          'CAF-UV'          100   100
    20:       -184.59445       162.666291                            100   100
    21:        -96.00000        15.000000                            100   100
     ASP:
     K  :      -1.000000     KC :      100
     IC :        YES         CUF:    0.000000    CCF:      100
     A  :0.000000E+00        B  :0.000000E+00    C  :0.000000E+00    D  :0.000000E+00
     AC :        100         BC :      100       CC :      100       DC :      100
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Table I (Continued)

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CODE V> lis
      Shafer-design .75NA,4x,75mm Obj.-hight
               RDY                  THI       RMD         GLA            CCY    THC    GLC
                                                                         ---    ---
        22:          INFINITY        24.980383                                  100    100
        23:        -247.00000        67.808099                                  100    100
          ASP:
          K  :     -1.000000     KC :      100
          IC :       YES         CUF:     0.000000     CCF:       100
          A  :0.000000E+00       B  :0.000000E+00      C   :0.000000E+00     D   :0.000000E+00
          AC :       100         BC :      100         CC :       100        DC :       100

        24:        -237.00000       266.861281                                  100    100
          ASP:
          K  :     -1.000000     KC :      100
          IC :       YES         CUF:     0.000000     CCF:       100
          A  :0.000000E+00       B  :0.000000E+00      C   :0.000000E+00     D   :0.000000E+00
          AC :       100         BC :      100         CC :       100        DC :       100

        25:        -470.62323      -266.861281  REFL                            100    100
        26:        -210.84570       266.861281  REFL                            100    100
          ASP:
          K  :      0.000000     KC :      100
          IC :       YES         CUF:     0.000000     CCF:       100
          A  :-.419940E-08       B  :-.904030E-13      C   :-.297400E-17     D   :-.106340E-21
          AC :       100         BC :      100         CC :       100        DC :       100

        27:          INFINITY        35.031723                                  100    100
        28:        1621.80000        33.000000          'CAF-UV'                100    100
          ASP:
          K  :      0.000000     KC :      100
          IC :       YES         CUF:     0.000000     CCF:       100
          A  :0.155580E-07       B  :-.854090E-12      C   :0.123240E-16     D   :-.559700E-21
          AC :       100         BC :      100         CC :       100        DC :       100

        29:        -747.60113        67.859320                                  100    100
        30:         827.21786        27.000000          'CAF-UV'                100    100
        31:       -1939.50000        20.227637                                  100    100
        32:         197.25357        14.999969          'CAF-UV'                100    100
        33:         128.31113        39.542169                                  100    100
        34:       -1370.10000        24.000000          'CAF-UV'                100    100
          ASP:
          K  :      0.000000     KC :      100
          IC :       YES         CUF:     0.000000     CCF:       100
          A  :-.164770E-07       B  :0.155510E-11      C   :-.542070E-16     D   :0.556740E-20
          AC :       100         BC :      100         CC :       100        DC :       100
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Table I (Continued)

```
CODE V> lis
       Shafer-design .75NA,4x,75mm Obj.-hight
                 RDY              THI       RMD        GLA           CCY    THC    GLC
     35:       -253.41246       18.476467
     36:        109.90063       30.001392          'CAF-UV'                 100    100
    STO:        242.23740       22.529315                                   100    100
     38:       -264.99438       46.219742          'CAF-UV'                 100    100
     39:       -372.29467        0.998929                                   100    100
     40:        173.30822       24.000000          'CAF-UV'                 100    100
          ASP:                                                              100    100
          K  :      0.000000   KC :       100
          IC :       YES       CUF:     0.000000    CCF:      100

          A  :0.628520E-07     B  :-.915530E-11     C  :-.628040E-15     D  :-.946620E-19
          AC :       100       BC :       100       CC :       100       DC :       100

     41:       1411.60000        4.845900                                   100    100
     42:        110.28842       22.740804          'CAF-UV'                 100    100
     43:        160.79657       13.371732                                   100    100
     44:         69.10873       45.185600          'CAF-UV'                 100    100
     45:       -895.78799       11.999039                                   100    100
          ASP:
          K  :      0.000000   KC :       100
          IC :       YES       CUF:     0.000000    CCF:      100
          A  :-.113590E-06     B  :0.281520E-09     C  :-.171880E-12     D  :0.507740E-16
          AC :       100       BC :       100       CC :       100       DC :       100

    IMG:          INFINITY         0.000000                                 100    100

       SPECIFICATION DATA
          NAO       -0.18750
          TEL
          DIM             MM
          WL          157.63      157.63      157.63
          REF              2
          WTW              1           1           1
          XOB        0.00000     0.00000     0.00000      0.00000      0.00000
                     0.00000     0.00000
          YOB        0.00000    26.51700    40.00000     53.03300     64.95100
                    70.15600    75.00000
          WTF        0.00000     0.00000     1.00000      1.00000      1.00000
                     1.00000     1.00000
          VUX        0.00000    -0.00138    -0.00308     -0.00534     -0.00803
                    -0.00941    -0.01082
          VLX        0.00000    -0.00138    -0.00308     -0.00534     -0.00803
                    -0.00941    -0.01082
          VUY        0.00000    -0.00065    -0.00224     -0.00398     -0.00520
                    -0.00531    -0.00535
          VLY        0.00000    -0.00370    -0.00706     -0.01156     -0.01709
                    -0.01985    -0.02220
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Table I (Continued)

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APERTURE DATA/EDGE DEFINITIONS
  CA
      APERTURE data not specified for surface Obj thru  46

PRIVATE CATALOG
  PWL              157.63      157.63      157.63
  'CAF-UV'       1.558411    1.558410    1.558409

REFRACTIVE INDICES
   GLASS CODE                  157.63      157.63      157.63
  'CAF-UV'                   1.558409    1.558410    1.558411

No solves defined in system

No pickups defined in system



   INFINITE CONJUGATES
      EFL     -66053.1391
      BFL     -16500.9052
      FFL      0.2642E+06
      FNO          0.0000
   AT USED CONJUGATES
      RED         -0.2500
      FNO         -0.6667
      OBJ DIS     34.0000
      TT        1198.5356
      IMG DIS     11.9990
      OAL       1152.5365
      PARAXIAL IMAGE
       HT         18.7496
       THI        12.0008
      ANG          0.0000
      ENTRANCE PUPIL
       DIA     0.3818E+10
       THI     0.1000E+11
      EXIT PUPIL
       DIA     25217.8299
       THI    -16501.3415
   CODE V> out t
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